CASE REPORT

EXTENSIVE BURN INJURY CAUSED BY FUNDAMENTAL ELECTRONIC CIGARETTE DESIGN FLAW

CAS CLINIQUE: BRÛLURE ÉTENDUE LIÉE À UN DÉFAUT DE CONCEPTION DE CIGARETTE ÉLECTRONIQUE

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SUMMARY. Currently, electronic cigarette (EC) devices are widely used as an alternative to conventional smoking. The underlying technical principle is an electric coil-based vaporizer unit, which vaporizes various solutions for inhalation purposes with a rechargeable lithium battery unit as power source. We report a case of extensive burn injury resulting from the thermal explosion of a battery unit within an EC device. Though internal thermal instabilities of lithium ion batteries are a known safety issue, the unique feature here is a pronounced amplification of the extent of burn injury due to an additional scalding burn mechanism that resulted from heating of the liquid reservoir adjacent to the battery. Thus, we demonstrate a relevant design flaw in various EC devices, which in the authors' opinion needs to be addressed both by manufacturers and safety regulations.

Keywords: electronic cigarette (EC), design flaw, lithium battery, burn, scald, adiabatic short circuiting

RÉSUMÉ. *Les cigarettes électroniques sont de nos jours très largement utilisées comme alternative au tabagisme. Le principe est la vaporisation aux fins d'inhalation d'un liquide chauffé par une résistance alimentée par une batterie au lithium, rechargeable. Nous rapportons un cas de brûlure étendue causée par l'explosion de la batterie, surchauffée. Si le risque d'explosion des batteries au lithium est bien connu en cas de surchauffe, la particularité ici est que le patient a en outre été ébouillanté par le e-liquide dont le réservoir était très proche de la batterie. Nous montrons ici un défaut de conception de certaines cigarettes électroniques qui devrait être pris en compte par les fabricants et les autorités.*

Mots-clés: *cigarette électronique, défaut de conception, batterie au lithium, brûlure, ébouillantement, court circuit, adiabatique*

Introduction

Electronic cigarettes (ECs) or electronic nicotine delivery systems (ENDS) are a widely used alternative to conventional smoking. Incentives to use ECs are: (i) a supposedly reduced health risk,[1] (ii) an aid to stop smoking,[2] (iii) they fall outside the scope of smoke-free legislation[3] and (iv) they are a personal life-style choice with various 'aromas' available, similar to water pipe devices.[4] Recent data estimate that in developed countries sporadic use of ECs by individuals below the age of 45 is >9% and regular (within 30 days intervals) use is >2% with a steady rise in recent years.[5,6]

Although still under debate, various publications[7,8] have addressed potential harmful effects related to the inhalation of vaporized liquids, nicotine-free or not. With this clinical case, we would like to call attention to the potential of ECs to cause severe burn injury due to underlying technical design features. The relevance of our findings are further underpinned by EC-induced technical design flaws in ECs leading to burn injury, recently reported in two other publications.[9,10] Regarding a pertinent risk evaluation, one has to be aware that there are various designs of ECs on the market[11,12] thus possible design flaws are likely to vary. The large majority of EC devices are manufactured in China. Four major designs varying in size are on the market: (1) a small, disposable cigarette-shaped device; (2) a small, rechargeable cigarette-shaped device; (3) a medium-size, pen-shaped rechargeable device; (4) a large, tank-style device. However, all EC designs share a common feature in that a battery has to be incorporated in close proximity to a reservoir containing the substance to be vaporized for inhalation. A schematic standard design of large tank-style devices is shown in *Fig.1*. Typically, vaporization is achieved by heating solutions inside an electric coil-based vaporizer/atomizer/clearomizer. Solutions/'e-liquids' usually contain propylene glycol (propane-1,2-diol) and/or glycerol (propane-1,2,3-triol) as a carrier for flavourings with or without nicotine

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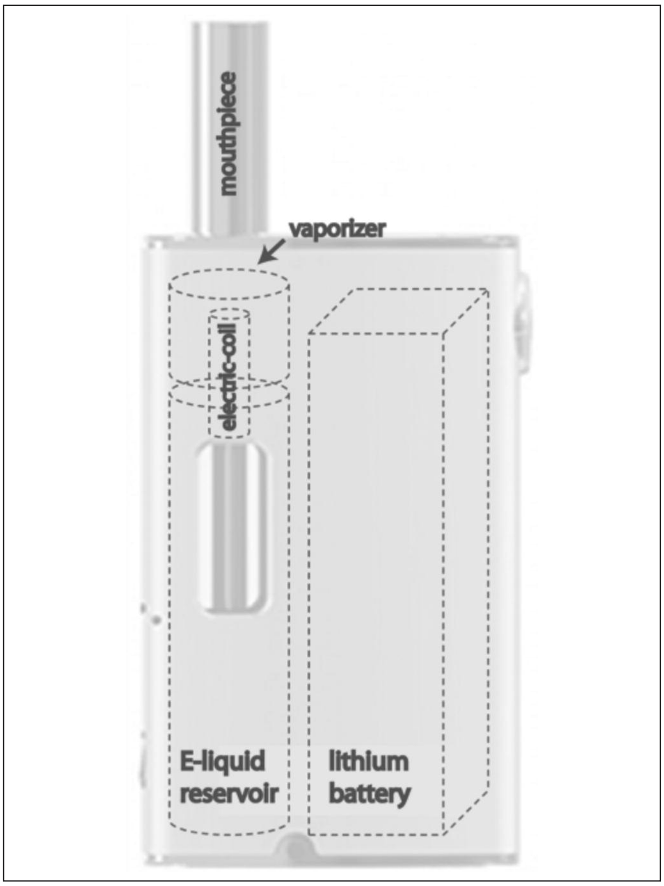

Fig. 1 - Illustration of a large tank-style EC device. Within the EC device, integrated lithium batteries typically provide an electric coil-based liquid vaporization unit with a voltage of <4V, <2.5A and a power-output of 5-50W. In the event of the battery short circuiting and thermal instability, the adjacent reservoir will act as a heat sink up to a critical point of thermal explosion.

as an additive. Flavouring substances may be water or alcohol (ethanol) soluble.[6] It is possible for end-users to modify inhalation products, including the use of cannabis or marijuana.[13] Commercially, propylene glycol contents of inhalation solutions commonly exceed 90%. It is important to note that the physical (sea-level) boiling point of alcohol is 78.37°C, water 100°C, propylene glycol 188.2°C and glycerol 290°C.

Case presentation

A 24-year-old male patient was admitted to the emergency department following a sudden 'explosion' along with a 'fire blaze' emanating from his right lateral trouser pocket. The explosion was caused by a large, tank-style EC device with a tank volume of 5ml that, according to the patient, contained 'nicotine-free e-liquid' watered down. Pre- and intra-operative evaluation showed a significant burn injury on his right leg with a IIa-b degree burn area of ~8% body surface area along with soot-particle contamination (*Fig. 2*) but no open wound or foreign body perforation. Initial surgical treatment was performed using DermaPrep™ debridement sponge and sterile application of SUPRATHEL® alloplastic (Lacto-capromer) absorbable skin substitute. A post-operative healing interval was uneventful, with no need for autologous skin graft or signs of contracture formation over a follow-up of 6 months.

Discussion

Along with other recent publications,[9,10] the case reported here demonstrates the potential hazard of the internal thermal instabilities of lithium ion batteries along with an adiabatic process of energy transfer. Lithium batteries are widely used in portable devices despite an inherent risk of internal short circuiting associated with lithium dendrite formation during cy-

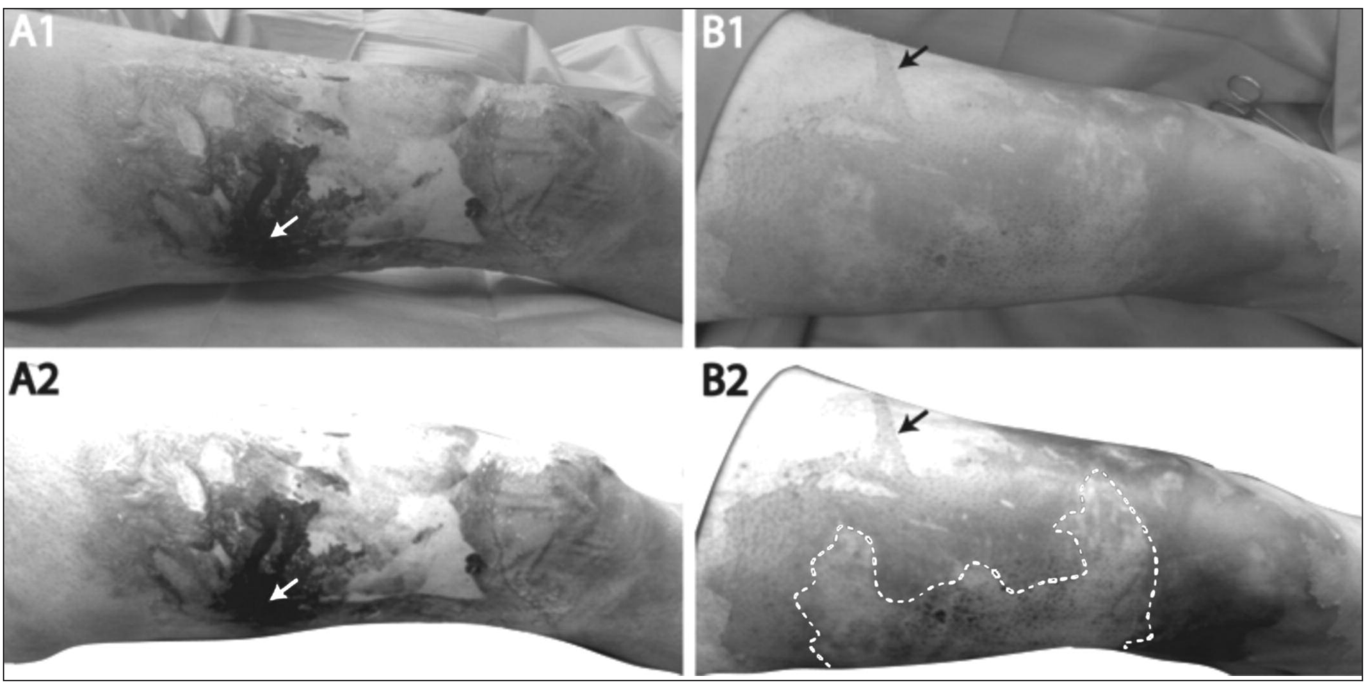

Fig. 2 - Thermal explosion-induced burn injury caused by battery unit failure of an Electronic Cigarette (EC) device. Burn injury to the right leg on admission with white arrows marking flame-induced, soot-particle covered burned areas opposed to surrounding scalded skin area (A1/2). Following surgical debridement, IIa degree areas can be distinguished from IIb degree areas within the white-dotted line marked areas. Black arrows demonstrate scalding marks due to hot liquid (B1/2).

cling.[14] Rapid internal short-circuiting can initiate high amounts of energy conversion into heat and adiabatic mechanical deformation. Experimental rapid-discharge studies on standard lithium batteries have demonstrated maximum temperatures of up to 903°C and pressures reaching 1565.9 psig (pound-force per square inch gauge) equivalent to a ~26kJ amount of energy reaction, resulting in thermal adiabatic explosion.[15] Thus, even without steep self-heating (dT/dt) and pressure rise (dP/dt) rates, internal short circuiting lithium batteries can easily reach temperatures of above 100°C over a sustained period of time.

In the case presented here, burn injury sustained from a tank-type EC device failure carried features of both burn and scald burn. Specifically, burn injury induced by an explosive combustion reaction in the lithium battery itself appeared to have been amplified by heat transfer, with over-boiling of the 'e-liquid' reservoir, resulting in a far larger area of scald burn injury. Also, the fact that the patient had diluted 'e-liquid' with water likely resulted in a reduction in the overall physical boiling point of the solution. Since wound-healing intervals were normal compared to conventional hot water scald injuries, an additional toxic effect of the 'e-liquid' on the burned skin in this case appears unlikely.

Conclusion

In summary, this case demonstrates that with large, tank-style electronic cigarette (EC) devices, several factors have the potential to cause severe burn injury when internal battery failure occurs: (i) the proximity of liquid reservoirs in ECs to lithium batteries, (ii) the volume of liquid reservoirs, (iii) the content of liquid reservoirs as well as (iv) the size and thus energy capacity of lithium batteries. We conclude that a re-evaluation of EC design and safety regulations is required.

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